National Aeronautics and Space Administration
John H. Glenn Research Center at Lewis Field

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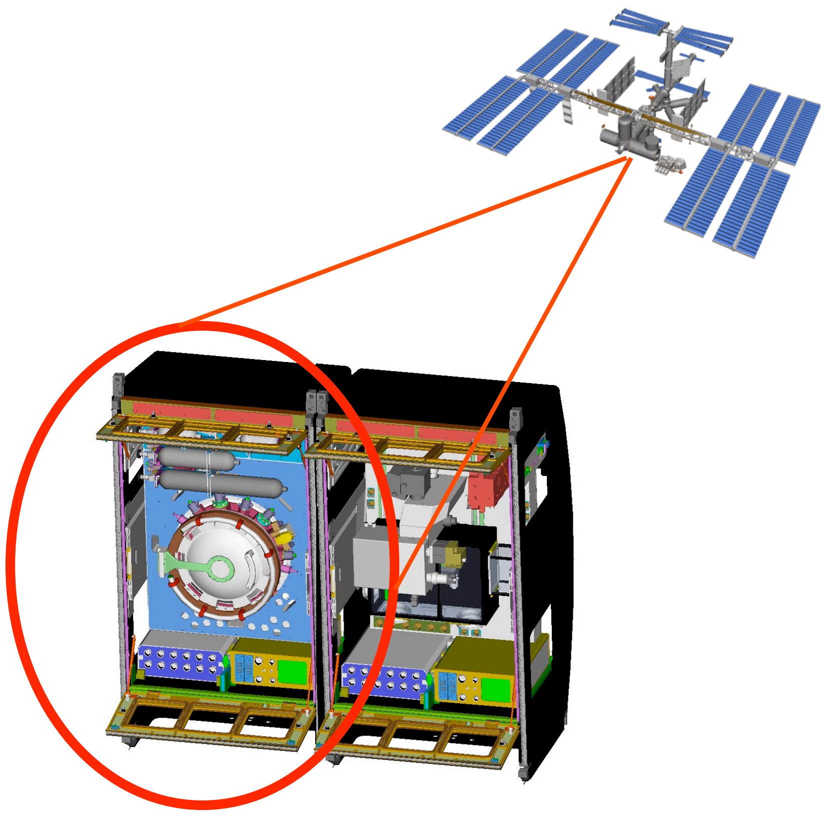
International Space Station Fluids and Combustion Facility Combustion Integrated Rack Payload Accommodations



Principal Investigator's Guide

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PREFACE

The International Space Station (ISS) will provide scientists from industry, academia, and the government with unparalleled opportunities for research in space. The ISS will enclose more than 1,716 cubic yards of pressurized space and house six dedicated laboratory modules. The primary facility for microgravity combustion research on-board the ISS will be the Fluids and Combustion Facility (FCF) Combustion Integrated Rack (CIR). This facility is being developed to support sustained, systematic research on-board ISS and will be capable of accommodating five to fifteen microgravity combustion experiments per year during the more than ten years that ISS will be operational after assembly complete. The accommodations are summarized in this document.

This document is intended to be used by Principal Investigators entering NASA's Microgravity Combustion Science Program and/or those investigators currently in the program who are seeking combustion experiment flight opportunities using the ISS. It broadly describes the microgravity combustion science program and future flight opportunities on-board ISS in the FCF CIR, and the planned capabilities of the CIR.

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I. MICROGRAVITY COMBUSTION SCIENCE PROGRAM

Combustion is a key element of many critical technologies used in society today such as electric power production, home heating, surface and air transportation, space propulsion, and materials synthesis (see Figure 1). Effects of gravitational forces impede combustion science studies, since combustion involves production of high temperature gases whose low density results in buoyant motion. Gravity, therefore, vastly complicates the execution and interpretation of combustion experiments. Gravity also causes particles and droplets to settle, inhibiting studies of heterogeneous flames. Combustion scientists use microgravity to simplify the study of combustion processes, leading to an enhanced fundamental understanding of combustion processes.

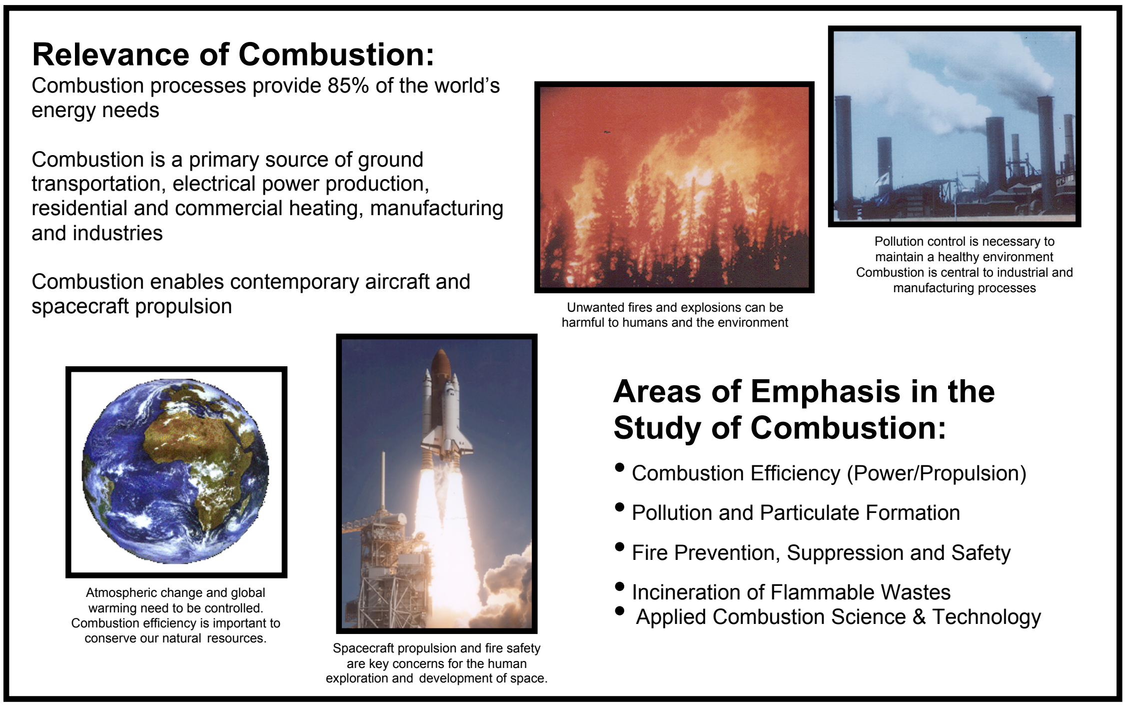

Figure 1. Combustion relevance and areas of emphasis.

The following areas of research are emphasized in the Microgravity Combustion Science Program (see Figure 2):

- Premixed gas flames
- Gaseous diffusion flames
- Combustion of liquid fuel droplets and sprays
- Combustion of solid particles and dust clouds
- Flame spread across liquid and solid fuel surfaces
- Smoldering combustion
- Combustion synthesis of materials

The Microgravity Combustion Science Program seeks a coordinated research effort involving both space-based and ground-based research. Ground-based research forms the foundation of the Program, providing the necessary experimental and theoretical framework for development of rigorous understanding of basic combustion phenomena. This research can eventually mature to the point where it becomes the focus of a well-defined flight experiment. More information on the Microgravity Combustion Science Program may be found on the Internet at http://microgravity.grc.nasa.gov/combustion/index.htm.

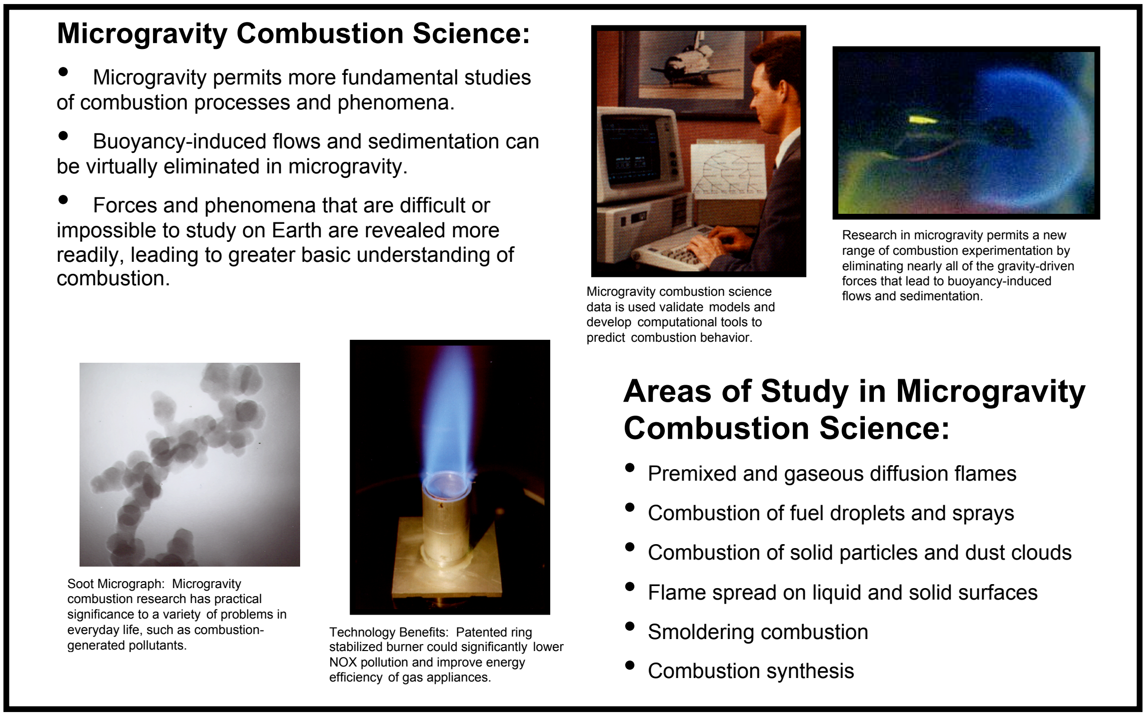

Figure 2. Areas of study in microgravity combustion.

The NASA research proposal solicitation process provides researchers from industry, academia, and government with the opportunity to apply for funding for combustion flight experiments and for ground-based experimental and theoretical research in microgravity combustion science. NASA Research Announcements (NRA) for microgravity combustion research and flight experiment opportunities are typically issued every year by the NASA Headquarters Office of Biological and Physical Research (OBPR). Investigations selected for flight experiment definition must successfully complete a number of subsequent development steps, including internal NASA and external peer review of the flight experiment in order to be considered for a flight assignment. More information may be found on the Internet at the following NASA OBPR web site: http://spaceresearch.nasa.gov.

II. MICROGRAVITY COMBUSTION RESEARCH PLATFORMS

Microgravity combustion science investigations are accomplished using a variety of research platforms that support both ground-based and flight investigations (see Figure 3). These research platforms have, in the past, included drop towers, aircraft flying parabolic trajectories, sounding rockets, and the Space Shuttle. In the future, the primary platform for microgravity combustion flight experiments will be the International Space Station.

The **2.2 Second Drop Tower** allows investigators to test experimental packages (up to 125 kg) in a microgravity environment for a period of 2.2 seconds. Experiments assembled on a drop frame structure are enclosed in a drag shield that has a high weight-to-frontal area ratio and a low drag coefficient. A gravitational acceleration of less than 10^{-4} g is obtained during the fall since the experiment package falls freely within the drag shield. Battery packs provide onboard power to the experiment. Data is acquired by high speed motion picture cameras (frame rates up to 1000 frames per second), video cameras, and on-board data acquisition systems used to record data supplied by thermocouples, pressure transducers, and flow meters. Normal operations provide the opportunity for 8 to 12 drops per day to be performed. More information on the 2.2 second drop tower may be found on the Internet at the following site: http://microgravity.grc.nasa.gov/drop2/.

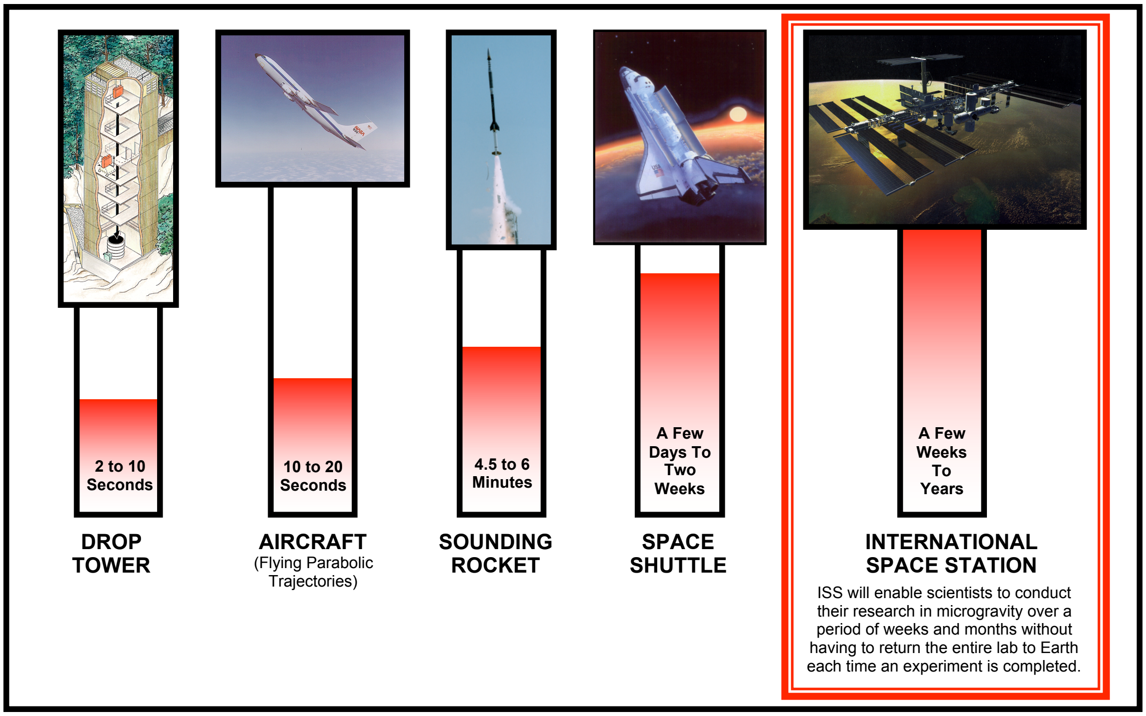

Figure 3. Microgravity research facilities.

The **Zero Gravity Research Facility** has a 132-meter free fall distance in a drop chamber that is evacuated by a series of pump down procedures to a final pressure of 1 Pa. Experiments utilizing hardware up to 450 kg are mounted in a 1 meter diameter by 3.7 meter high drop bus. Gravitational acceleration less than 10^{-5} g is obtained for 5.18 seconds. Visual data is acquired through the use of high speed motion picture and video cameras. Other data such as pressures, temperatures, and accelerations are either recorded on board with various data acquisition systems or are transmitted to a control room by a telemetry system capable of transmitting 18 channels of continuous data. Due to the complexity of facility operations and time required for pump down of the drop tube, typically only one test is performed per day. More information on the Zero Gravity Research Facility may be found on the Internet at the following site: http://microgravity.grc.nasa.gov/zero-g/index.html.

Reduced-gravity aircraft are flown in parabolic arcs to achieve 20 to 25 seconds of microgravity. The aircraft obtains a low-gravity environment by flying a parabolic trajectory. As many as 40 parabolic trajectories may be performed on a typical flight. Gravity levels twice those of normal gravity occur during the initial and final portions of the trajectory, while the brief pushover at the top of the parabola produces less than one percent of Earth gravity (10^{-2} g). Free-floated experiments can experience 10^{-3} g for periods up to 10 seconds. Several experiments can be integrated in a single flight. Both 28 volt DC and 100 volt AC power are available to accommodate a variety of experiments. Instrumentation and data collection capabilities must be contained in the experiment packages. More information on reduced gravity aircraft may be found at the following Internet site: http://microgravity.grc.nasa.gov/KC_135/index.html.

Sounding rockets produce higher quality microgravity conditions for longer periods of time than airplanes. Microgravity conditions vary with the rocket type and payload mass. Sounding rockets are divided into two parts: solid-fuel rocket motor and payload. The payload is the section that carries the instruments to conduct the experiment and sends the data back to Earth. NASA currently uses 15 different sounding rockets. These rockets can carry payloads of various weights to altitudes from 30 miles (48 km) to more than 800 miles (1287 km). Scientific data are collected and returned to Earth by telemetry links, which transfer the data from the sounding rocket payload to the researchers on the ground. In most cases, the payload parachutes back to Earth, where it is recovered and reused. Normal operations provide the opportunity for an average of 30 NASA sounding rocket launches each year. Additional information on sounding rockets may be obtained at the following Internet site: http://www.wff.nasa.gov/pages/soundingrockets.html.

The **Space Shuttle** is a reusable launch vehicle that can maintain a consistent orbit and provide up to 17 days of high quality microgravity conditions. The Shuttle, which can accommodate a wide range of experiment apparatus, provides a laboratory environment in which scientists can conduct longer-term microgravity investigations. A number of primary microgravity combustion flight experiments performed in the past decade used the Space Shuttle as a platform. Locations on the shuttle are the middeck lockers (lockers used in the middeck area of the Orbiter cabin), get-away specials (small self-contained payloads in cylindrical containers located externally), or in Spacelab/SPACEHAB laboratories located in the cargo bay of the Space Shuttle. As NASA proceeds from the Shuttle era to the Space Station era, fewer microgravity combustion experiments will be conducted on-board the Shuttle and microgravity research activities will transition to ISS. Information on the Space Shuttle may be found at the following Internet site: http://spaceflight.nasa.gov/shuttle/.

The **International Space Station** is a semi-permanent facility that will maintain a low Earth orbit for up to several decades. The International Space Station will afford scientists and engineers a unique on-orbit research facility, in which complex, long-duration experiments can be performed. The ISS will enable scientists to conduct their research in microgravity over a period of several months without having to return the entire laboratory to Earth each time an experiment is completed. The primary carrier of microgravity combustion experiments in ISS will be the Fluids and Combustion Facility (FCF) Combustion Integrated Rack (CIR). General information about the International Space Station may be found at the following Internet site: http://spaceflight.nasa.gov/station/.

III. ISS FLUIDS AND COMBUSTION FACILITY

The ISS Fluids and Combustion Facility (FCF) is a modular, multi-user facility that will support microgravity fluid physics and microgravity combustion science research on-board the International Space Station (see Figure 4). The FCF will be a permanent on-orbit research facility that will enable NASA's Human Exploration and Development of Space (HEDS) Microgravity Program objectives to be met. The FCF is being designed to support sustained, systematic research in the ISS over the ten to fifteen year lifetime of ISS, after its assembly has been completed on-orbit. The facility is being designed to accommodate 5 to 15 fluid physics experiments per year and 5 to 15 combustion science experiments per year, depending upon ISS resources and Microgravity Research Program resources that are made available to support investigations in these research disciplines.

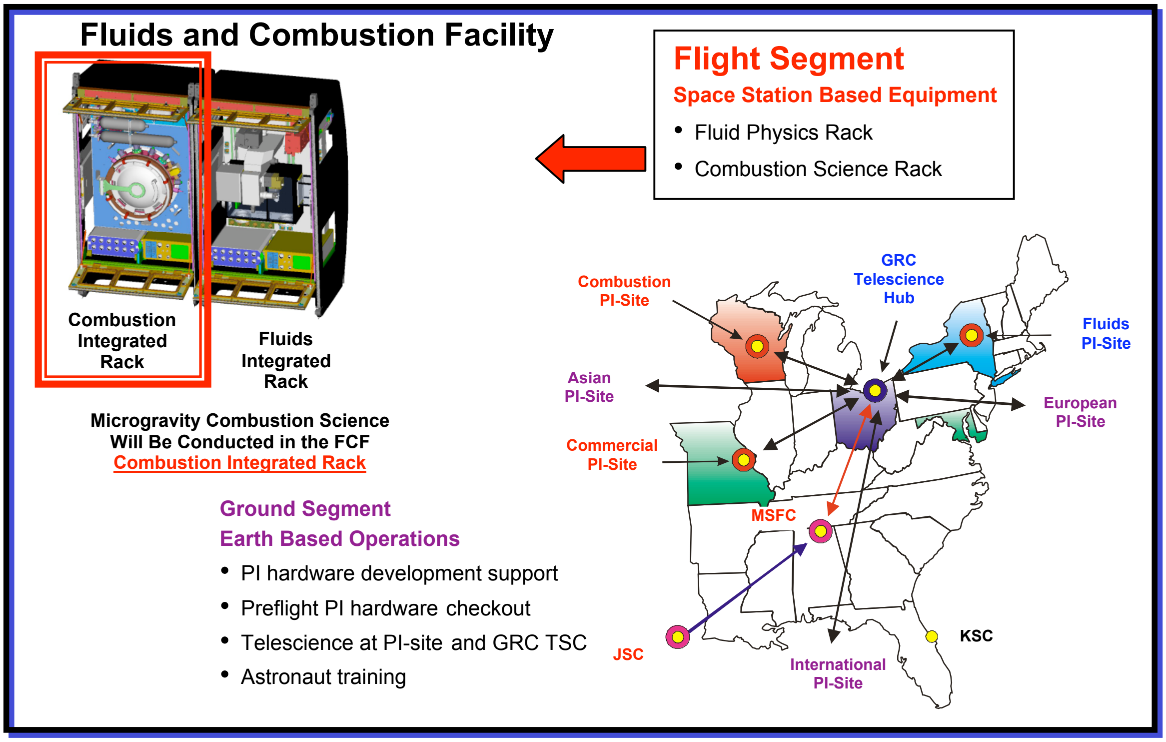

Figure 4. Fluids and Combustion Facility operations concept.

The FCF Flight Segment will consist of two on-orbit racks that will be located inside the US Laboratory Module of the ISS. These racks are the Combustion Integrated Rack (CIR) and the Fluids Integrated Rack (FIR). The Combustion Integrated Rack will be optimized to support a diverse range of microgravity combustion science investigations on-board the ISS. It will be the first FCF rack deployed to ISS and is currently planned for launch to ISS on ULF-2 in 2004. The CIR will initially operate independently from the other FCF rack, supporting the first set of microgravity combustion science investigations on board ISS. After the FIR is deployed to ISS, the CIR will operate in conjunction with that rack to leverage their capabilities, thereby maximizing combustion experiment through-put and science return from ISS. More information on the FCF may be found at the following Internet site: http://fcf.grc.nasa.gov.

IV. FCF COMBUSTION INTEGRATED RACK

The FCF Combustion Integrated Rack (CIR) will provide a platform for sustained, systematic microgravity combustion science research on-board the ISS. Principal investigators will be able to use this microgravity environment to isolate and control gravity-related phenomena, and to investigate processes that are normally masked by gravitational effects and thus are difficult to study on Earth. A diverse range of combustion research can be accommodated in the CIR, including but not limited to studies of laminar flames, reaction kinetics, droplet and spray combustion, flame spread, fire suppressants, condensed phase organic fuel consumption, turbulent combustion, soot and polycyclic aromatic hydrocarbons and material synthesis.

The CIR will provide the majority of required hardware and infrastructure to perform combustion science investigations in ISS. In this way the cost and development requirements for individual experimenter's hardware is minimized. However, key components of the CIR will be on-orbit replaceable items to enable it to be customized for each new combustion experiment that will be performed in it. The CIR's modular, flexible design will also permit upgrades, incorporation of new technology, and provide for on-orbit maintenance during the > 10 year life span of the facility.

A Principal Investigator that plans to use the CIR as a research platform for combustion experimentation will typically develop science-specific equipment that will be installed in the CIR to perform the experiment (see Figure 5). The following types of hardware and software items may be needed to tailor the CIR to accomplish the specific research objectives of a microgravity combustion experiment: intrusive diagnostics (thermocouples), igniters, fuel samples, combustion chamber insert, experiment gases (contain in FCF-provided bottles), exhaust vent filter(s), science-specific diagnostics, specialized electronics, and control software (scripts).

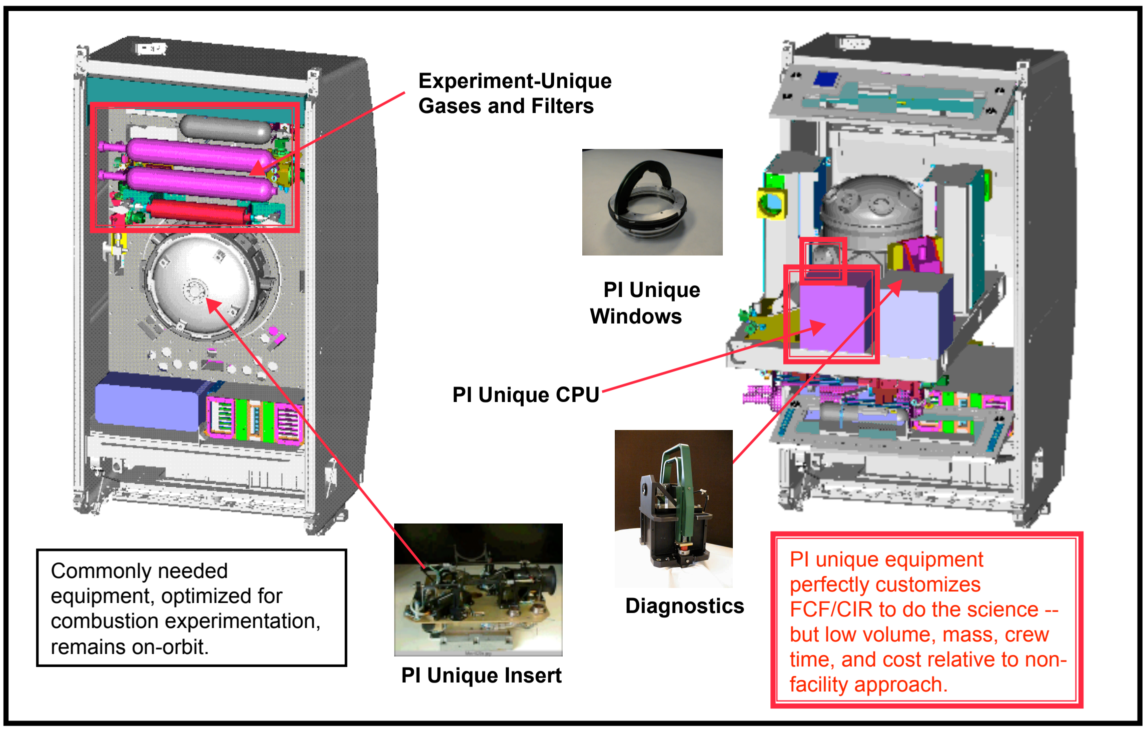

Figure 5. The CIR works with PI-unique and experiment specific hardware and software.

V. CIR ELEMENTS AND SUBSYSTEMS

The CIR consists of many elements and subsystems (see Figure 6.) It will provide an optics bench for combustion experimentation in the ISS. The layout of the bench can be optimized for each new combustion experiment. A 100-liter combustion chamber is located in the center of the optics bench. It incorporates eight windows that can be replaced on orbit. Windows will be selected for the wavelengths of light most important to the PI and/or changed out if contaminated. The CIR's Fuel Oxidizer Management Assembly (FOMA) will deliver gaseous fuels, oxidizers, and diluents to the combustion chamber. The FOMA can support static and dynamic mixing of gases with very high precision and accuracy. This assembly also provides for access to vacuum and cleaning of combustion by-products to make them safe to vent overboard after the experiment is conducted. The composition of gases in the combustion chamber will be measured using the CIR Gas Chromatograph. Illumination sources and cameras covering a wide spectral range for various scientific measurements can be mounted outside each combustion chamber window on the optics bench. These cameras and light sources can be removed and replaced quickly, with all electrical and data connections made upon crew installation. Their operation will be by remote control from Earth.

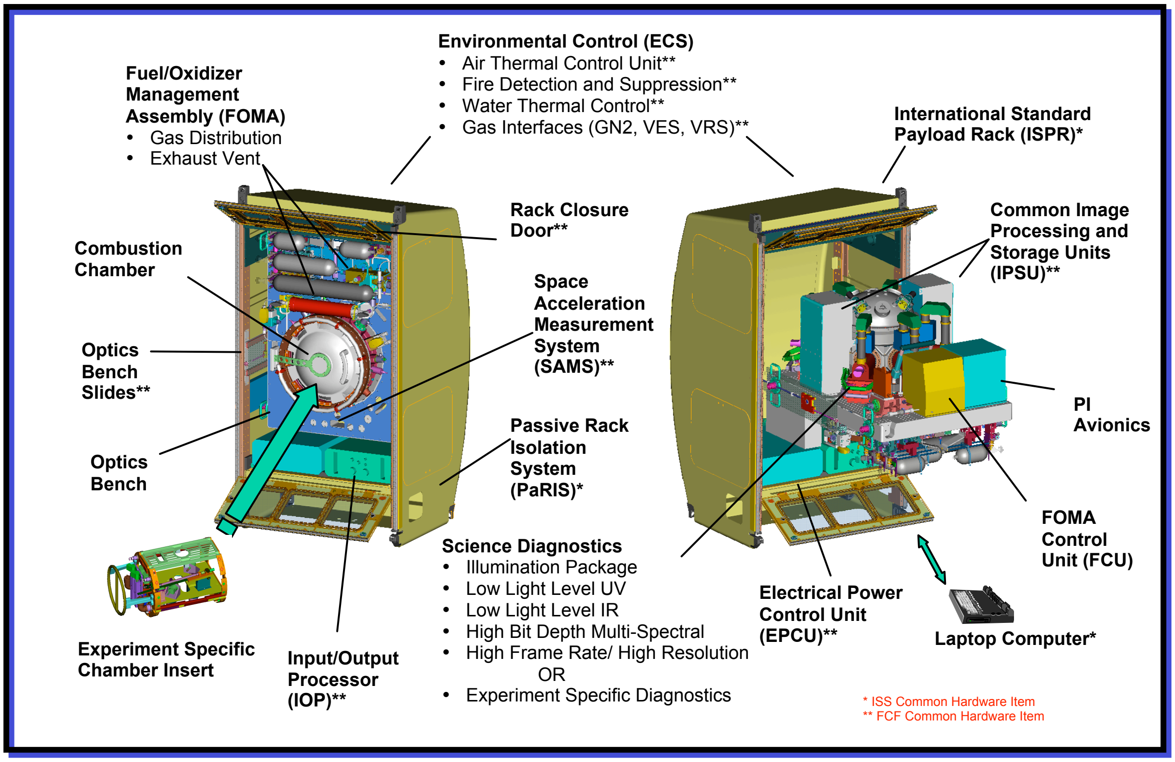

Figure 6. Major Combustion Integrated Rack Subsystems.

VI. CIR RESOURCES AND USER INTERFACES

Table 1 summarizes the structural, mechanical, cooling, nitrogen, vacuum exhaust, fire detection and suppression, gaseous supply, gas chromatograph, diagnostics, command data and software interfaces to the payloads. The document FCF-IDD-CIR, Combustion Integrated Rack Payload Interface Definition Document, contains additional information.

Table 1. Summary CIR interfaces to payloads.

Discipline	Standard Accommodation	Remarks
Structural/ Mechanical	Includes as a minimum: • Chamber insert mounting to the Combustion Chamber • Principal Investigator (PI) Avionics Package mounted on rear of Optics Bench. • Universal Mounting Locations (UMLs) at each Combustion Chamber window for mounting PI Diagnostics Packages.	• The chamber insert, PI Avionics Package and PI Diagnostics must conform to installed center of gravity (CG), modal frequency, and envelope volume limits. • Eight windows made of sapphire. • Rear end ports. • MDP of chamber is 135 psia.
Electrical/Power	• 28 VDC power provided through UMLs. • 120 VDC power provided through rack outlet.	• Equipment in the Multi-Purpose Logistics Module (MPLM) will not be powered for ascent/descent.

Discipline	Standard Accommodation	Remarks
Thermal Control / Cooling[1]	• Cooling air provided through UML openings for Diagnostic Packages and PI Avionics Packages based on heat load. • Cooling water available to chamber insert from the Combustion Chamber and to Diagnostics Packages on the rear of the Optics Bench.[2]	• Use of cabin air for cooling is prohibited. • CIR payloads connect to coolant through flexible lines and self sealing liquid quick-disconnect fittings.
Nitrogen[2]	• An ISS-provided Gaseous Nitrogen (GN2) interface is provided to the Combustion Chamber and the rear of the Optics Bench through the Fluid/Oxidizer Management Assembly (FOMA).	• CIR to provide interfacing Quick Disconnects (QDs) and fluid lines.
Vacuum Exhaust[2]	• An ISS-provided Vacuum Exhaust System (VES) interface is provided to the Combustion Chamber through the Fluids/Oxidizer Management Assembly (FOMA). • The Exhaust Vent Package (EVP) provides the ability to filter particles, adsorb combustion by-products to acceptable levels, remove any moisture and allow for a re-circulation loop in and out of the Combustion Chamber. Major components of the EVP are the adsorber cartridge and re-circulation pumps. • Combustion Chamber oxygen concentration and pressure control.	• Provides bulk gas removal capability. • CIR to provide interfacing Quick Disconnects (QDs) and fluid lines. • Waste gas and trace contaminants must be within the limits defined by the ISS.
Fire Detection and Suppression	• The Fire Detection and Suppression Subsystem (FDSS) provides detection and suppression of fire events within the CIR. • The CIR independently monitors for smoke using a smoke detector.	• The CIR provides air circulation to assure appropriate air sampling around the payload components. • The smoke detector is ISS developed hardware. The smoke detector uses laser light attenuation and laser light scattering to detect smoke. Upon detection of a fire event with the CIR, dispersion of a CO_2 fire extinguisher will be accomplished via normal air-cooling paths within the rack.
Gas Supply and Distribution	• The Gas Supply and Distribution Package (GSDP) consists of gas supply bottles and the necessary hardware/instrumentation to distribute and regulate the gas delivery to the Combustion Chamber. The desired gases are contained in the FCF-provided flight bottles (1.0, 2.25, and 3.8 Liter sizes).	• Safety requirements dictate the maximum oxygen concentration in each of the three bottle sizes. • On-orbit blending will be accomplished by the GSDP using three methods: pre-mixed bottles, partial pressure, and dynamic mixing. All of these methods can be used to pressurize the chamber to the desired pressure and gas ratio. GSDP can support on-orbit gas blending with up to three gases (up to 3 bottles or 2 bottles and ISS supplied nitrogen). The non-fuel gases can be blended on-orbit, but fuel bottles are required to be either pure or pre-mixed and be filled on the ground.
Gas Chromatograph (GC)	• The Combustion chamber environment can be sampled using the GC Package. The GC can provide information on the gases inside the Combustion Chamber before or after the combustion process. The GC will include three independent separation columns and thermal conductivity detectors. The column shall be selected based upon the compounds that are to be analyzed.	• The current design will include a Molecular Sieve column, which is used to separate fixed gases such as oxygen, nitrogen, carbon monoxide, hydrogen, helium, and methane. • The second column will be a Poraplot Q column that is used for analysis of fixed gases and light hydrocarbons, carbon dioxide, methane, ethane, ethylene, and C3 hydrocarbons. • The third column is an OV 1701 column that is used to separate mid-polar compounds by boiling point. This column will be used for hydrocarbons C4 and higher and for low molecular weight alcohols.
Diagnostics	• CIR provides standard imaging, illumination and diagnostics devices for use by the payload. • Pressure, temperature, and acceleration are provided. • Payload-provided diagnostics will attach to the various CIR interfaces.	• High Bit Depth/Multi-spectral Imaging Package, High Frame Rate/High Resolution Package, Low Light Level UV Package, Low Light Level IR Package, Illumination Package. • Diagnostic Modules and Common Image Processing and Storage Units (C-IPSU)

Discipline	Standard Accommodation	Remarks
Command and Data	• Interfaces available at the UMLs include Ethernet, CAN Bus, Fiber Optic, and analog video. • Interfaces for processing analog and digital I/O are provided. • IEEE 1394 (Fire wire) interface available at the Common Image Processing and Storage Unit.	• CIR to provide interfacing through UMLs. • Video compression is performed in eh IPSU. • Ground commanding and data downlink is available. • Input/Output Processor has two removable 180 GB hard drives. • Common IPSU has two 36 GB hard drives.
Laptop and Software	• Space Station Support Computer (SSC) laptop to be shared by FCF and all payloads. • FCF-provided application Programming Interface (API) will be available to implement commands/telemetry from the SSC.	• Software is loaded on a SSC. • Payload-unique Graphical User Interface (GUI) software and icons are Payload Developer developed and verified.

1. Additional active/forced air-cooling required beyond what the CIR provides is the responsibility of the Payload Developer.
2. These resources/accommodations are limited in quantity and will need to be time-lined to eliminate conflicts and/or incompatibilities.

1. Optics Bench

The Optics Bench provides structural support, electrical connections, and mounting locations for all science support hardware. The bench is mounted on slide assemblies for fold down to facilitate access to both sides as shown in Fig. 6. The bench contains 8 Universal Mounting Locations (UML) for diagnostic package mechanical and electrical interfaces providing common power, command/control and data collection, air cooling, structural mounting and optical alignment (see Fig. 7). The packages can be positioned on the bench with an alignment accuracy of 100 microns. One additional UML is provided for exclusive use of the experimenter's avionics box. This location is labeled the PI location. All tubing and wiring is internal to the bench. Fiber optics cabling runs across the bench, connecting diagnostic packages and image processing and storage units.

2. Combustion Chamber/Chamber Insert Assembly

The Combustion Chamber is a pressure vessel designed to withstand 135 psia of maximum design pressure (MDP). The maximum capacity is 100 liters. The Combustion Chamber accepts a Chamber Insert Assembly (CIA) with maximum dimensions of 600 mm in length and 396 mm in diameter. The chamber contains eight 115 mm dia. field of view replaceable windows allowing for simultaneous orthogonal views. The standard baseline window material is sapphire (Al_2O_3), which has a transmission wavelength range of 0.25 to 5.5 microns.

The blue area in Fig. 8 indicates the region into which a CIA may be placed. Areas in red indicate areas that may be used but require consultation with FCF. White areas indicate locations of known protrusions into the chamber volume.

The CIA mounts to the chamber using two rails located inside the chamber (see Fig 9). Two sets of rails are provided, positioned 22.5^o above and below the horizontal axis of the chamber. This allows the CIA to be positioned in two different orientations and make use of all eight windows if necessary without the need of reconfiguration of diagnostics. The chamber rails provide accurate positioning of the CIA with high repeatability. Rail parallelism is kept with 250 microns from front to back of the chamber. Accuracy for CIA centering with respect to the center of the chamber is 100 microns.

The chamber also provides two ports of 63.5 mm diameter in the rear end cap for additional chamber access. These ports can be utilized for additional windows or ports if the experiment requires them. A 43.5 mm dia. area is left after the space required for the O-rings is subtracted.

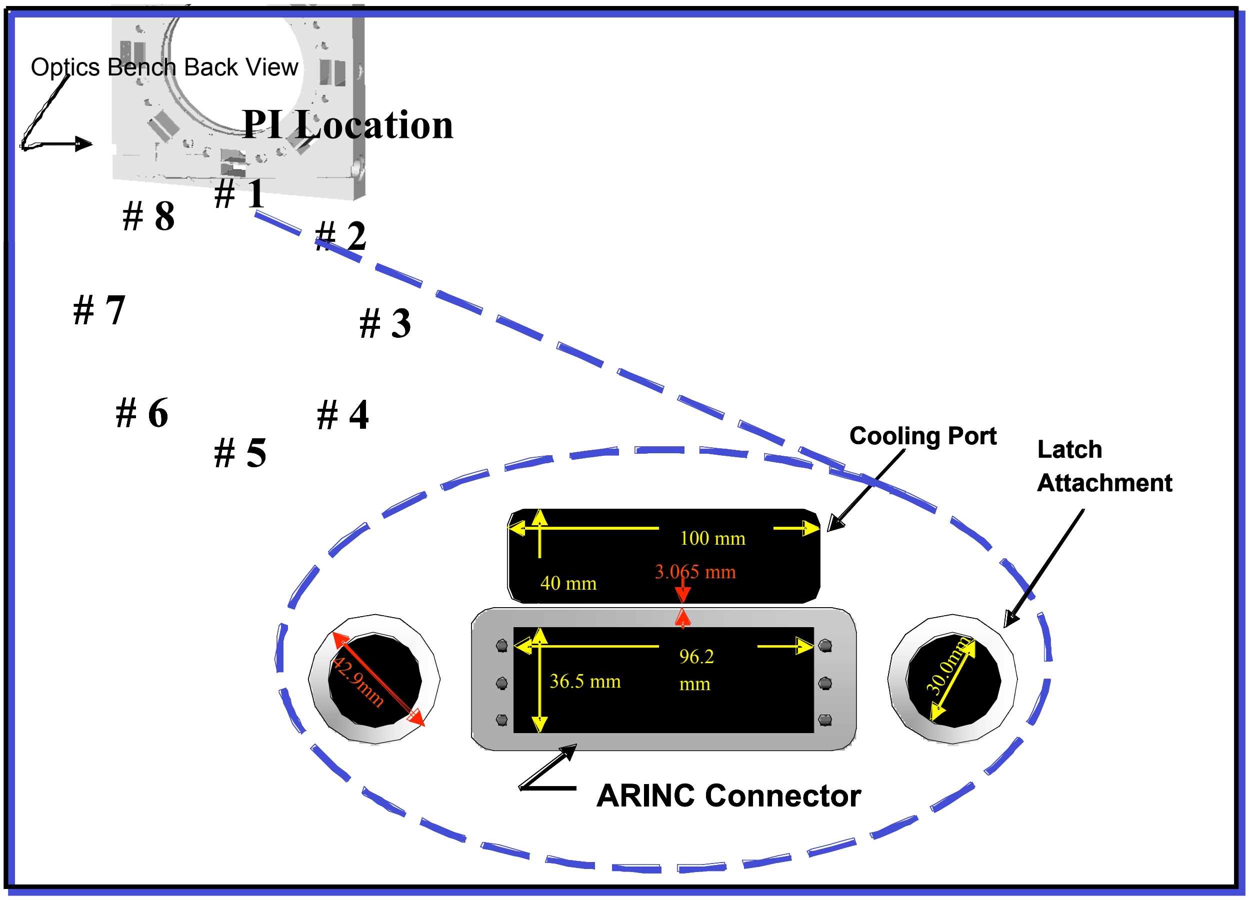

Figure 7. Optics Bench with Universal Mounting Location positions.

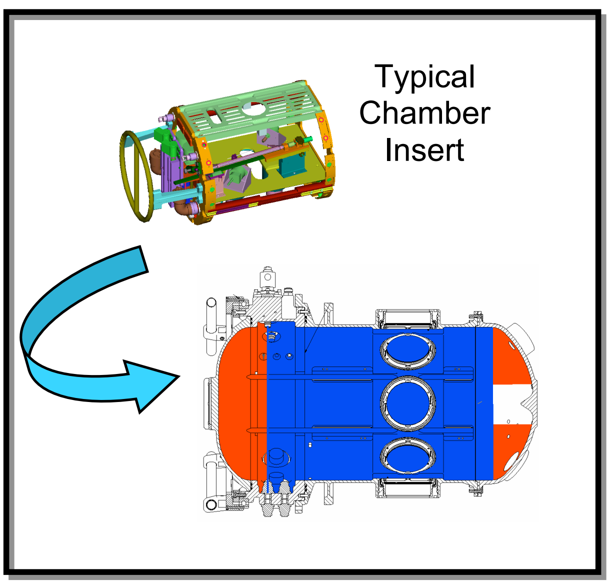

Figure 8. A typical chamber insert assembly installs into the combustion chamber through the front end cap.

The electrical and fluids interfaces between the combustion chamber and the CIA is achieved through the Interface Resource Ring (IRR). Fluid connections allow injection of fuel, oxidizer, and diluent into and exhaust from the chamber. In addition, a line for ISS-supplied water is provided for CIA cooling if needed. Notches are cut in the minor diameters of the IRR to allow the CIA to interface with the chamber. This interface is designed to prevent the CIA from extending over the IRR and to protect the electrical connections and instrumentation.

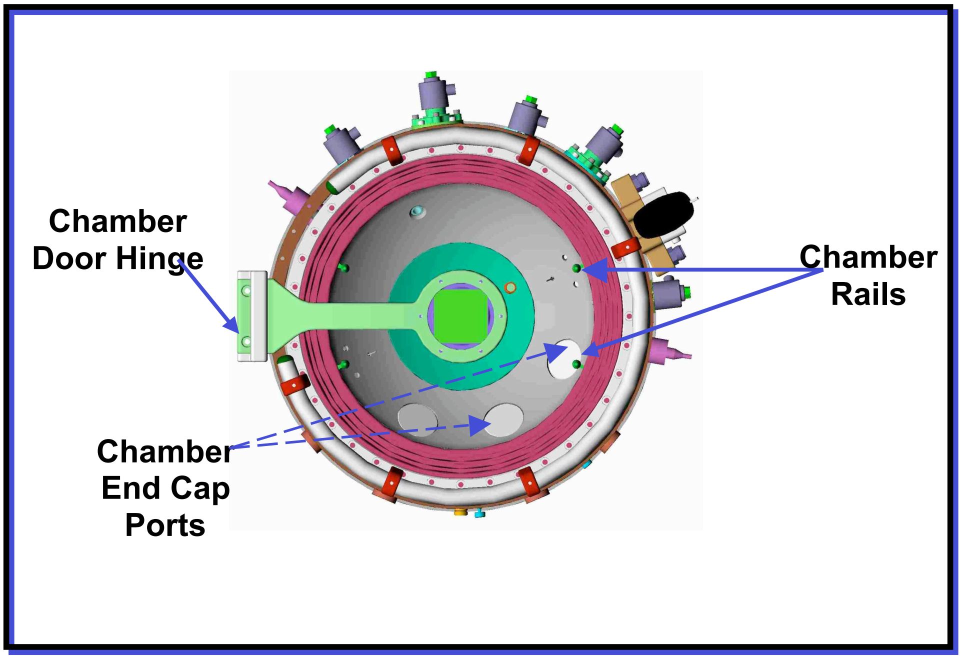

Figure 9. Combustion chamber cross section.

3. Fuel/Oxidizer Management Assembly (FOMA)

The FOMA provides the ability to safely deliver all gaseous fuels, diluents, and oxidizers required to perform combustion experiments in the chamber. The FOMA can also sample the test chamber environment via a Gas Chromatograph (GC) and control venting of chamber gases, at acceptable concentration levels, to the ISS Vacuum Exhaust System (ISS VES). The FOMA consists of two packages: the Gas Delivery Package (GDP) and the Exhaust Vent Package (EVP) which includes the GC.

The desired gases are supplied by the experimenter in CIR-provided bottles. The gases can be either premixed or pure. The FOMA provides the interface by a quick disconnect attachment to the manifold for the bottles. The FOMA can also provide ISS-supplied nitrogen in place of a bottle. The crew will be able to change out bottles when required. The bottles sizes are 1.0 L, 2.25 L, and 3.8 L. They are commercially-available stainless steel with a maximum pressure of 14 MPa (2000 psig). The maximum concentration of oxygen in a bottle is 85%, 50%, and 30%, respectively, for the three bottle sizes. Fuels may be contained in the 1.0 and 2.25 L bottles.

The FOMA also regulates and controls gas flow to the chamber. The fuel line is completely isolated from the oxidant line. The maximum fuel flow rate is 2 SLM (based on propane). The maximum oxidizer or diluent flow rate is 30 SLM from each of three manifolds for a total flow rate of 90 SLM.

The FOMA can provide on-orbit gas blending of up to three gases by two methods: partial pressure and dynamic mixing. The accuracy of partial pressure gas mixing is +/- 0.2% absolute; the dynamic mixing accuracy is +/-1% absolute for oxygen blends less than 25% and +/- 2% of reading for oxygen blends greater than 25%.

The FOMA can accommodate static or flow-through type experiments. For static experiments, the desired gas mixture fills the chamber and then the experiment is run. For flow-through experiments, the desired flow during a combustion experiment is supplied along with real-time venting to maintain a constant pressure in the combustion chamber. Real-time venting is a once-through flow method where flow is vented overboard and not recirculated. It may be used for experiments which do not produce unacceptable gaseous byproducts or experiments that can have their byproducts cleaned to acceptable levels by a single pass through the adsorber cartridge.

An adsorber cartridge/recirculation loop is used to clean post-combustion gases. The adsorber cartridge material is provided by the PI. A recirculation loop and the adsorber cartridge convert post-combustion gases into species that are acceptable to vent, or to improve the test gas environment for the next experiment run. The cartridge is 76.2 mm ID x 355 mm long. It has quick disconnect attachments for crew replacement. The adsorber cartridge may contain silica gel for the removal of water, alcohols, aromatics, and olefins, molecular sieve for the removal of water, activated carbon for the removal of hydrocarbons, and lithium hydroxide for the removal of carbon dioxide and acid gases.

The gas chromatograph is used to sample and measure the contents of the combustion chamber. The current design will include a Molecular Sieve column, which is used to separate fixed gases such as oxygen, nitrogen, carbon monoxide, hydrogen, helium, and methane. The second column will be a Poraplot Q column that is used for analysis of fixed gases and light hydrocarbons, carbon dioxide, methane, ethane, ethylene, and C3 hydrocarbons. The third column is an OV 1701 column that is used to separate mid-polar compounds by boiling point. This column will be used for hydrocarbons C4 and higher and for low molecular weight alcohols. A GC check gas is experiment-provided. The lower detection limit of the GC is 100 ppm (depending on the compound and the gas mixture) with an expected accuracy of +/- 2% of reading.

4. Avionics, Power, and Thermal

The Input/Output Processor (IOP) performs the command processing, control, data processing, data management, caution and warning, health and status monitoring, and time synchronization for the CIR. The IOP provides all of the data and communication paths to and from the ISS, as well as between other subsystems within the CIR. Two 181-GB hard disks are provided for data buffering and storage. These drives are removable from the front of the IOP for replacement or returning data to Earth. A PI Avionics Box is provided by the experimenter. It is intended to provide tight, closed-loop control of PI specific equipment such as the CIA in addition to providing data acquisition and signal conditioning for PI-provided diagnostics.

The Electrical Power Control Unit (EPCU) performs power distribution, conversion, control, management, and fault protection functions. The CIR offers 28 VDC at the UMLs, the PI location, and the chamber. It also offers 120 VDC, 1.92 kW at the rear of the rack.

All packages mounted on the optics bench are air cooled by the CIR Air Thermal Control Unit. Air is supplied to the packages through the optics bench air ports at 77 ^oF (25 ^oC). The system removes up to 1650 W of waste thermal energy. Water cooling is provided to the combustion chamber interior or the rear of the optics bench by the Water Thermal Control Unit at a temperature of 65 ^oF (18.3 ^oC). The minimum cooling capability is just over 6 kW.

5. Diagnostics

The CIR offers five diagnostic packages for use. They are in the modular form. This allows for the independent design and configuration of optical subassemblies that can be combined to form multiple packages and fulfill the requirements of many experimenters thus minimizing the amount of on-orbit hardware. The five packages are the High Frame Rate/High Resolution (HFR/HR) Package, High Bit Depth Multi-Spectral (HiBMs) Package, Low Light Level UV (LLL-UV) Package, Low Light Level IR (LLL-IR) Package, and the Illumination Package. Table 2 lists the feature and capabilities of the assembled CIR packages and their applications.

Table 2. CIR diagnostic packages summary.

Package	Application	Pixels	FOV (mm)	Resol. (lp/mm)	Bit Depth (bits)	Run Time (min.)	Frame Rate (fps)	Spectrum (nm)	Sensitivity	Features
HiBMs	Soot Volume Fraction, Soot Temp., Shadowgraph	1024 or Bin 512	80 dia. 50 sq. Telecentric	5 10	12	20	15	650 to 950	1200 K to 2000 K	Manual iris
HFR/HR	High Frame Rate, High Resolution	1024 or Bin 512	9 sq. (35 total) Telecentric	12 28	8	15	30 100 binned	450 to 650	600 lux	Centroid tracking, Auto-focus, Event trigger
Low Light Level UV	OH emissions, CH emissions	1024	50 80	16 20	8	20	60	250 to 700	6x10E-9 ft-candle	Manual iris and focus
Low Light Level IR	H_2O Emissions	1024	50 330	7 1	8	20	60	400 to 900	4X10E-9 ft-candle	Manual iris and focus
Illumination	Calibration, Background illumination	N/A	90 dia. Collimated	NA	NA	NA	NA	670 nm	NA	Diode source

Each diagnostic package interfaces to a Common Image Processing and Storage Unit (IPSU). The CIR provides four of these units. The Common IPSUs are computer systems tailored to perform data acquisition from cameras, data storage, image processing, and control. All data is stored in digital format. There are two types of Common IPSUs: one can accept Serial Data Link and IEEE 1394 inputs, the other can accept IEEE 1394 and analog inputs. The Common IPSUs are Compact PCI and Pentium based and include a Digital Signal Processor and acquisition board. The Common IPSUs support a wide range of digital camera formats and they can be located in all CIR UMLs. All Common IPSUs provide an analog output for image display to the Station Support Computer if display to the crew is required.

CIR provided packages can also be replaced by PI provided hardware if required. They must fit within the envelope shown in Fig. 10.

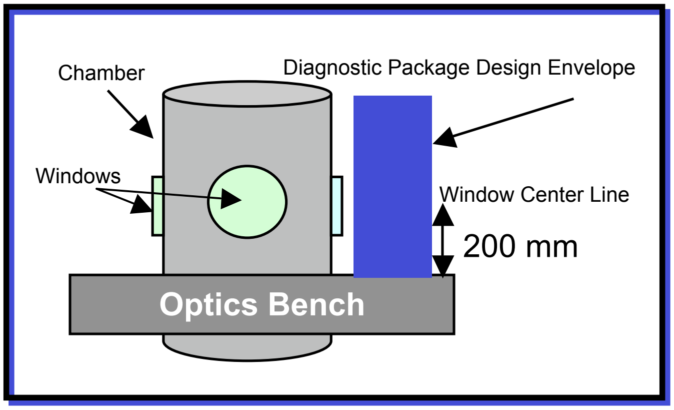

Figure 10. Diagnostic package envelope relative to the chamber.

In addition, a Space Acceleration Measurement System (SAMS) Triaxial Sensor Head (TSH) will be used to measure the acceleration environment in the rack. The unit has an adjustable frequency bandwidth from 0 to 200 Hz under software control. The full scale range is up to 0.78 milli-g.

VII. PI EXPERIMENT DEFINITION

The flow chart in Fig. 11 illustrates the process for selected experiments to be accommodated in the CIR aboard ISS. (This process may not be applicable for international partner experiments.) This process contains several reviews and milestones starting with the Science Concept Review (SCR) and the Requirements Definition Review (RDR).

After selection for the flight program, an experiment will enter the experiment definition phase. The purpose of this phase is to establish the science concept. The primary review in this phase is the SCR. The purpose of the SCR is to establish that the scope and feasibility of the experiment have been adequately addressed and to propose a definitive flight experiment. A well-defined and clearly written Science Requirements Document (SRD) is crucial for a successful SCR. The SRD, written for both peer scientists and engineers, describes the scientific justification, the need to conduct the experiment in microgravity, and the necessary requirements for the experiment. The SRD does not, however, contain detailed concepts or engineering drawings of the proposed experiment.

Assuming that it is determined that the investigation should be carried out with at least some hardware built specifically for that experiment, the activity then enters the hardware definition phase. The focus of this phase is to define the baseline hardware concept necessary to conduct the experiment and to establish the project baseline, including the project planning documentation. The primary review in this phase is the RDR. The purpose of the RDR is to baseline the science requirements, assess the conceptual design and engineering feasibility, and assess the project planning. The SRD is finalized after the RDR. Upon successful completion of this phase, the authority to proceed is given for flight development. At this point, a significant emphasis is placed on engineering activities associated with design, fabrication, assembly, and testing of the flight instrument.

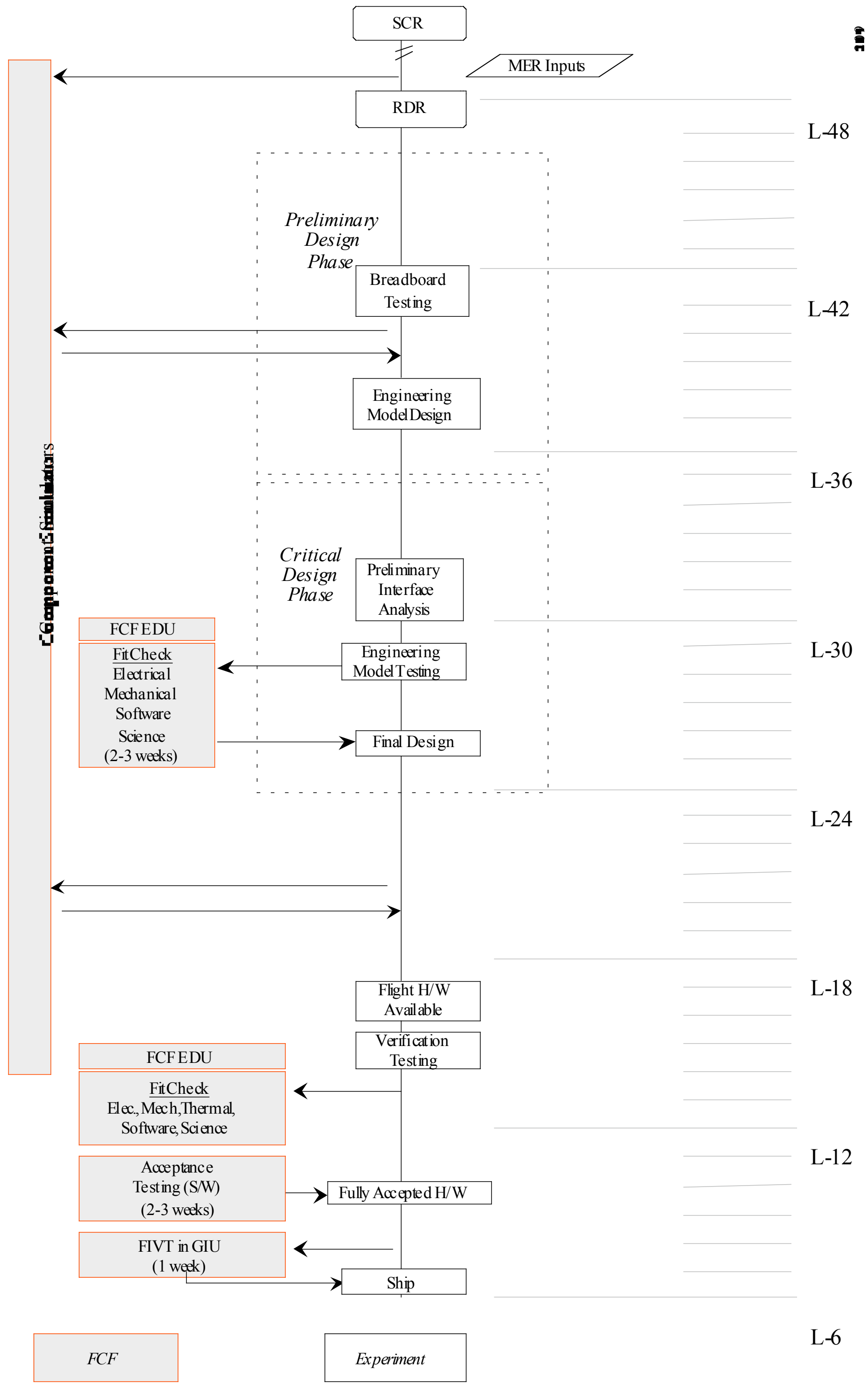

Figure 11. Flow chart for experiment integration into the CIR.

Management of the hardware development phase (Preliminary Design Phase and Critical Design Phase) is the responsibility of the Project Manager. During this phase, the hardware is designed, fabricated, assembled, and tested. Included in the testing are the science verification tests to insure that the hardware can perform the functions required to meet the science requirements of the various experiments. Standard flight hardware development design reviews, such as the Preliminary Design Review, the Critical Design Review, and the Preship Review, occur during this phase. Procedures for flight experiment, mission timeline, and crew training are developed. Development concludes with the delivery of the flight hardware for mission integration at KSC.

VIII. PAYLOAD PROCESSING AND INTEGRATION SUPPORT

1. Support Hardware

An extensive amount of ground support equipment will be made available to support processing, integration, and check-out of the Principal Investigator's experiment hardware and software prior to flight. In addition to the on-orbit CIR flight rack, there will be three additional supporting racks on Earth. They are a Ground Integration Unit (GIU), an Experiment Development Unit (EDU), and a Payload Training Center Unit (PTCU).

The CIR GIU will be located at GRC and will be used for final interface verification testing of experiment hardware, as well as for on-orbit troubleshooting. The GIU will be virtually identical to the flight unit.

The CIR EDU will be a high fidelity model very similar to the flight model. It will be located at GRC and made available to experiment developers during their hardware and software development and pre-flight testing. This unit will be used for interface verification and configuration selection testing.

The PTCU, which will be deployed at the Payload Training Center at Johnson Space Center, supports crew training. It will contain flight-like crew interfaces, and be comprised of mock-ups, brass board level components, and other non-flight components. The PTCU will include a standard experiment trainer that can be used to train on the installation of a generic experiment chamber insert or modular experiment computer. The PTCU will be supplemented with experiment-specific part task trainers, as necessary, that may be required to train the crew on the operation and maintenance of the experiment hardware.

2. Experiment Integration and Operation

Because the CIR hardware is designed to reduce the overall cost of individual experiments by providing substantial common capabilities, the experiment equipment alone cannot perform the scientific objectives of the experiment. Therefore, a multi-tiered integration support scheme, consisting of CIR simulator, experiment engineering, and experiment flight hardware integration testing is envisioned.

Simulators of CIR flight hardware will be available to experiment developers during the development of their hardware. Simulator equipment will be designed to emulate those interfaces between the facility and the experiment that must be tested early and often throughout the experiment development, so as to assist in the design of the experiment hardware and software. Simulators for the CIR will be produced to simulate, at a minimum, electrical and command and data handling interfaces, and be used extensively for interface verification testing between the facility and the experiment.

Simulators of available CIR configurable equipment, such as cameras, light sources, filter cartridges, etc. will also be provided for PI use. Early in the experiment development cycle, the CIR configurable equipment will require evaluation for suitability for use on a particular experiment. In addition to this engineering evaluation, diagnostic simulators may be required to support science testing prior to the experiment RDR.

Once a particular piece of CIR configurable equipment has been selected for use by an investigator, the experiment developer must conduct testing to optimize the configuration of the equipment. This testing will be used to select the settings, parameters, test sequence, and overall configuration of the CIR configurable equipment.

The next level of integration support is testing between experiment engineering hardware and the CIR EDU. This testing will satisfy the following objectives: interface verification, preliminary science acquisition, preliminary CIR configuration and parameter selection, test sequence identification, and crew procedure validation. This testing will nominally occur 24 months prior to launch, and is expected to last two to three weeks for each experiment.

Eventually, the experiment flight equipment will be integrated into the EDU to satisfy the following objectives: interface (mechanical, electrical, thermal, software, and fluid) verification, ground science acquisition, final CIR configuration and parameter selection, final test sequence identification, PI familiarization training, and experiment acceptance testing. A flight-like user interface will be provided at this stage of the integration testing. This testing will nominally occur 15 to 9 months prior to launch, and is expected to last two to three weeks for each experiment.

The last level of integration support, which provides the highest fidelity integration testing platform, is referred to as the Final Interface Verification Testing (FIVT). Completely tested and accepted experiment equipment will be integrated into the GIU. This test will consist of high-fidelity interface verification, and will include an abbreviated mission simulation in order to fully exercise the software interface. This test will last approximately one to three days and occur approximately one to two months prior to shipping the hardware to KSC. The hardware and software configurations will be frozen at the successful conclusion of this test. If any changes in hardware or software are required after the FIVT, the FIVT will normally be repeated.

Command and control of microgravity combustion experiment conducted on-board the ISS in the CIR will be orchestrated from the Telescience Support Center located at the Glenn Research center.

Some PI's may require additional ground data to supplement the actual microgravity data obtained aboard the ISS. If necessary, the EDU will support additional science acquisition, on a non-interference basis. This testing, when necessary, is expected to last approximately one to two weeks.